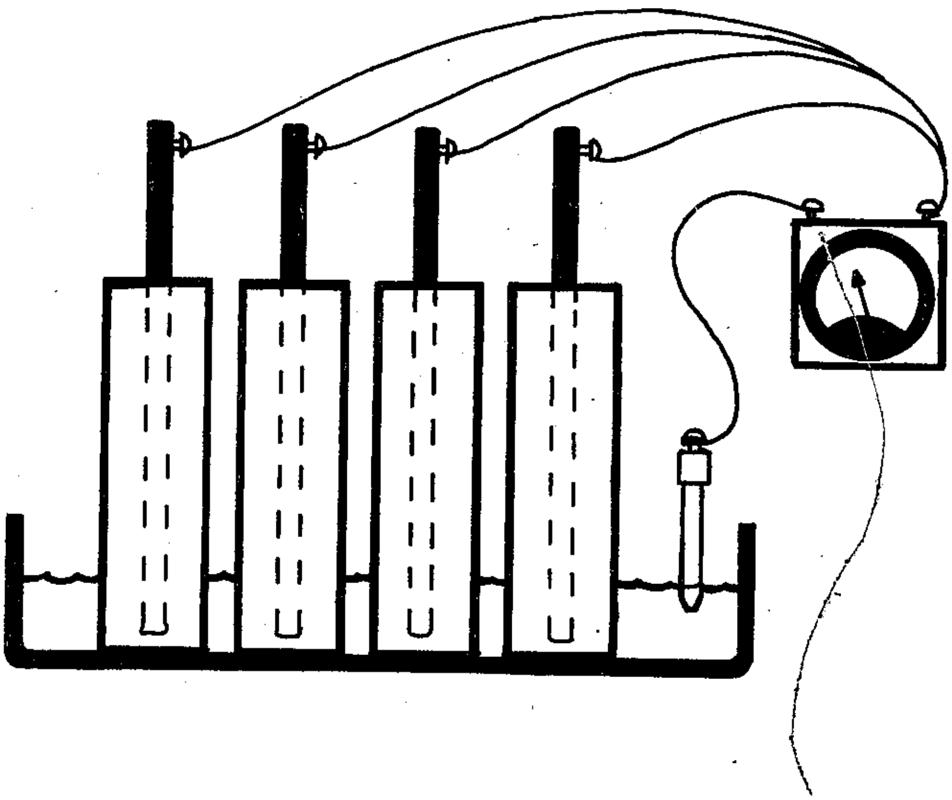
REPORT NO. CALTRANS/TL-79/18

CORROSION RESISTANCE OF INTERNALLY SEALED, POLYMER IMPREGNATED, AND POZZOLAN/PORTLAND CEMENT REINFORCED CONCRETE



Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

FINAL REPORT
AUG. 1979

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NOTE: The pozzolan used in this project was "AIROX" calcined shale

TECHNICAL REPORT STANDARD TITLE PAGE

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16. ABSTRACT

This report presents the findings of a 3.5 year laboratory study to determine the effects of special concrete treatments on the corrosion resistance of rinforced concrete (7-sack per cu. yd., moist cured).

The treatments were: 1) Internally Sealed Concrete (addition of wax beads to the mix, heating to melt the wax). 2) Polymer Impregnated Concrete (Monomer impregnation, heating to polymerize). 3) Pozzolan/ Portland Cement Concrete (15% and 30% Pozzolan in lieu of cement). After curing and treatments, specimens were partially submerged in salt water tanks and monitored for 3.5 years.

Half-cell potential measurements indicate that all treatments delayed the onset of corrosion 2 to 2.7 times longer than untreated specimens. Visual inspections indicate that Polymer Impregnated and low-Pozzolan treatments resisted initial cracking 3 to 4 times longer than the untreated specimens, with less than 20% of specimens exhibiting cracks after 3.5 years. Over 60% of the high- (30%) pozzolan specimens are exhibiting cracks, and over 80% of the Internally Sealed specimens are exhibiting cracks at the end of the 3.5 year test period.

It should be noted that differing cement factors, steam curing, and differing heat treatments may alter these results.

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

August 1979

TL No. 641139

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

CORROSION RESISTANCE OF INTERNALLY SEALED, POLYMER IMPREGNATED, AND POZZOLAN/PORTLAND CEMENT REINFORCED CONCRETE.

Study made by .... Electrical, Corrosion, & Engineering Services Branch

Under the Supervision of .... Donald L. Spellman, P.E.

Principal Investigator .... John A. Apostolos, P.E.

Report Prepared by .... John A. Apostolos, P.E.

Very truly yours,

Neal Andersen

NEAL ANDERSEN
Chief, Office of Transportation Laboratory

JAA:db

Attachment

TABLE OF CONTENTS

	Page
INTRODUCTION	1
CONCLUSIONS	2
PROCEDURE	4
1. Preparation of Specimens	4
2. Testing of Specimens	5
TEST RESULTS	7
DISCUSSION OF TEST RESULTS	8
REFERENCES	13
APPENDIX A: Corrosion Specimen Mix Designs	14

INTRODUCTION

A research program was initiated in the fall of 1975 to determine the effects of three special concrete treatments on the corrosion of reinforcing steel and subsequent distress of the concrete. These treatments were:

1. Internally Sealed Concrete (Wax beads added to concrete mix. Heat applied to concrete after curing, to melt the wax and thus fill or coat the internal voids.)

2. Polymer-Impregnated Concrete (Monomer impregnation of mature concrete, then heating to polymerize the monomer.)

3. Pozzolan/Portland Cement Concrete (Two concrete mixes with cement consisting of 85% Portland cement + 15% Pozzolan and 70% Portland cement + 30% Pozzolan.)

4. Control normal concrete (non-air entrained).

Normal laboratory test methods consist of casting concrete specimens with an embedded reinforcing steel rod and, after curing, placing them into tanks containing salt-saturated water. Monitoring the electrical potential of the embedded steel vs. standard electrodes allows determination of the onset of corrosion, which is indicated by a sharp change, or "jump", in the measured voltages. As corrosion progresses, the buildup of corrosion products creates tensile stresses in the concrete, which eventually causes the concrete to crack. Visual monitoring of the specimens allows determination of the onset of cracking.

Comparison of the "time to corrosion" and "time to cracking" of test specimens vs. normal concrete specimens, receiving identical exposure to salt water, allows evaluation of experimental treatments.

CONCLUSIONS

Based on observations of laboratory specimens tested under severe conditions (i.e., in salt water tanks) for 3.5 years, the following conclusions are drawn:

1. Polymer Impregnated concrete proved significantly superior to normal concrete in delaying the onset of corrosion. After corrosion had begun, cracking was observed much less frequently than in the normal specimens.*

Polymer Impregnated concrete is significantly superior to normal (7-sack) concrete in resisting corrosion-caused distress.

2. Pozzolan 15% + Portland 85% cement concrete proved superior to normal concrete in delaying the onset of corrosion.** After corrosion had begun, cracking was observed somewhat more frequently than in the normal specimens.

At this time, with 16% of the low-Pozzolan specimens cracked vs. 12% of the normal (7-sack) specimens, both may be judged equal in performance.

3. Pozzolan 30% + Portland 70% cement concrete proved superior to normal concrete in delaying the onset of corrosion.** After corrosion had begun, cracking was observed more frequently than in the normal specimens.

High Pozzolan + Portland cement concrete is significantly inferior to normal (7-sack) concrete in resisting corrosion-caused distress.**

4. Internally Sealed concrete proved significantly superior to normal concrete in delaying the onset of corrosion. After corrosion had begun, cracking was observed with a much higher frequency than in the normal specimens.

Internally Sealed concrete is significantly inferior to normal (7-sack) concrete (and to the other treatments) in resisting corrosion-caused distress.

*After the onset of corrosion, the frequency of cracking would be influenced to a large extent by the tensile strength of the concrete. The weaker specimens would tend to crack first. It is also possible, however, for weak, porous concrete to delay cracking, by allowing corrosion products "space" in which to expand.

**A previous study(1) indicated that steam-cured, 24% pozzolan + 76% portland cement concrete was significantly superior to normal concrete in delaying the onset of corrosion. (It is to be noted that, conversely, steam curing usually accelerates the onset of corrosion in normal concrete.) The time-to-cracking of the steam-cured specimens was not recorded.

PROCEDURE

1. Preparation of Specimens

A total of 120 test specimens were prepared as follows:

Type of Treatment	No. of Specimens
Control PCC	25
Internally Sealed (Wax)	25
Polymer-Impregnated	25
Pozzolan-Portland Cement 15:85	25
Pozzolan-Portland Cement 30:70	20

Each specimen consisted of a block measuring 2.5 x 4.5 x 15 inches (63 x 114 x 381 mm) and contained a 20 inch long, 0.5 inch diameter smooth steel reinforcing bar (508 x 12.7 mm) embedded 14 inches into the concrete (355 mm). The placement of the bar resulted in 1 inch of concrete cover to the steel (25 mm).

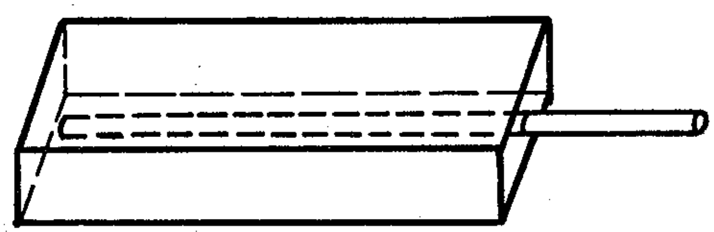


Figure 1. Typical Test Specimen

All 120 specimens were designed with a mix containing 7 sacks cement per cubic yard of concrete, using 3/4 inch maximum size aggregate (19 mm). The pozzolan-containing specimens contained 5.96 and 4.9 sacks of Portland cement per cubic yard, in order to adjust for the 15% and 30% of Pozzolan

substitutes respectively, and still maintain 7 sack (total pozzolan + portland cement) mix. Water was adjusted to provide uniform slump of 3 to 4 in.

2. Testing of Specimens

After maturing, and given the appropriate treatments, all specimens were placed vertically in saturated salt water tanks, to a depth of 3.5 inches (90 mm), leaving the remainder of the concrete, and the protruding steel bar above the water level.

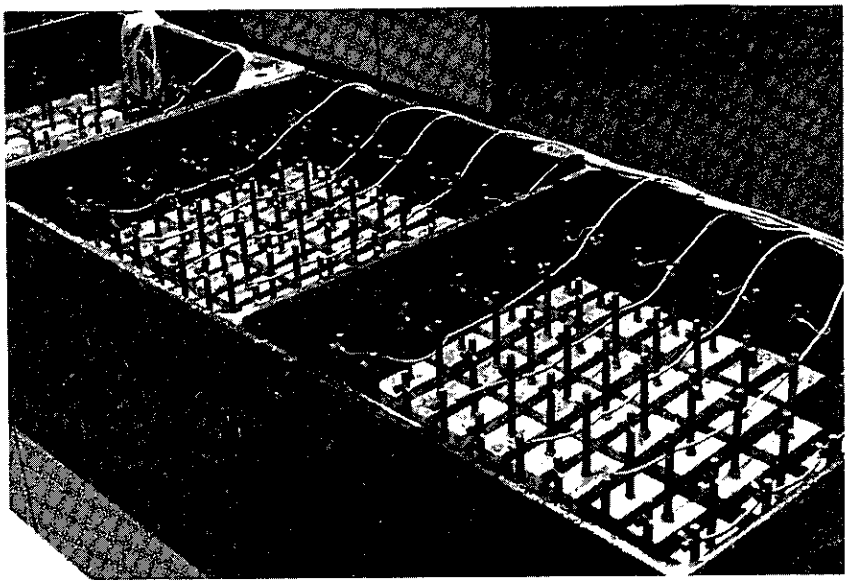


Figure 2. Specimens in salt water tanks. Wires connect the steel bars to automatic potential recording devices.

All specimens were kept in the salt water continuously, except for brief periods of surface cleaning during the visual crack surveys.

Half-cell potentials were monitored on a regular basis, using a Calomel (mercury-mercurous chloride) standard reference electrode, and automatic recording devices.

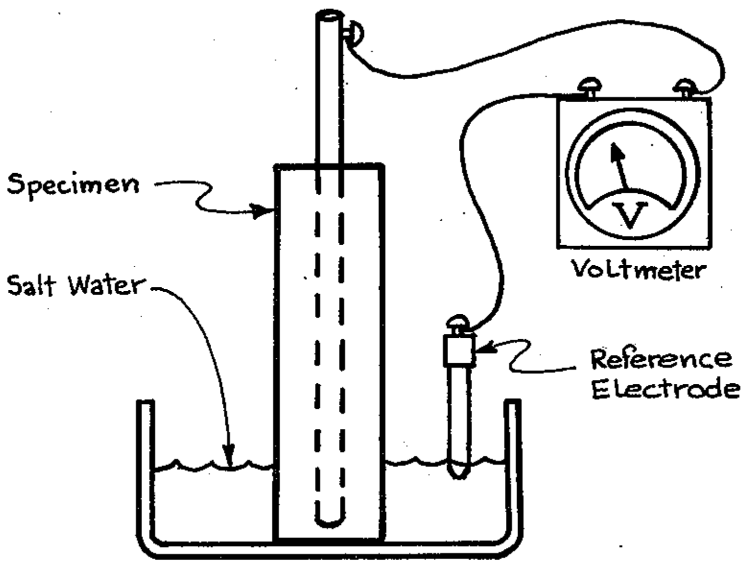


Figure 3. Schematic of immersed specimen being tested for half-cell potential.

During the 1283 days of monitoring (from 10/29/75 to 5/4/79) a total of 239 potential readings and 10 crack surveys were taken of each specimen.

TEST RESULTS

The following tables present the statistical behavior of the test specimens.

TABLE A. Time to onset of corrosion, and present condition of lab specimens in salt water.

Type of Concrete Mix or Treatment	No. of Days to Onset of Corrosion: First Specimen	10% of Specimens	50% of Specimens	90% of Specimens	100% of Specimens	% Corroding after 3.5 years
Control (Normal)	70	112	147	172	172	100%
Polymer Impregnated	98	240	400	847	1279	100%
Pozzolan 15%	30	267	400	501	637	100%
Pozzolan 30%	116	197	307	494	508	100%
Internally Sealed	277	277	299	733	755	100%

TABLE B. Time to onset of corrosion-induced cracking, and present condition of lab specimens in salt water.

Type of Concrete Mix or Treatment	No. of Days to Onset of Cracking: First Specimen	10% of Specimens	50% of Specimens	90% of Specimens	100% of Specimens	% Cracked after 3.5 years
Control (Normal)	314	405	-	-	-	12%
Polymer Impregnated	1276	-	-	-	-	4%
Pozzolan 15%	1271	1271	-	-	-	16%
Pozzolan 30%	1014	1014	1267	-	-	60%
Internally Sealed	319	319	1018	-	-	84%

DISCUSSION OF TEST RESULTS

Table A, Time to onset of corrosion of specimens in salt water, provides a measure of the ability of the concrete cover to resist salt water intrusion under laboratory conditions. Whereas 50% of the control normal concrete specimens were indicating corrosion after 147 days, the treated specimens reached the same condition after 299 to 400 days, (i.e., an average delay of 5 to 8 months under accelerated conditions). Clearly, all treatments under study do delay the onset of corrosion, with the Polymer Impregnation method being the best, followed by the Internally Sealed method and the 15% Pozzolan + 85% Portland Cement method.

It should be noted, however, that determination of onset of corrosion is based on measurements of electro-chemical potentials, which are influenced to some extent by the electro-chemical resistance of concrete. The extent to which this resistance is in turn influenced by each type of treatment, and consequently, the effect each treatment has on the potential measurements, is not precisely known. This uncertainty is mitigated by the observation of the onset of cracking.

Table B, Time to onset of corrosion-caused cracking of specimens in salt water, provides a comparative measure of the properties of each treatment. Cracking is influenced by the quantity of corrosion products formed from the steel and by the tensile strength of the concrete. The combined effect of these properties result in hastening or delaying the onset of distress.

Table B indicates that after 1273±5 days (3.5 years) in salt water, only 4% of the Polymer Impregnated specimens have cracked, vs. 60% of the high-Pozzolan + Portland cement, 16% of the low-Pozzolan + Portland cement, and 12% of the control specimens. Internally Sealed specimens exhibited the poorest performance, with 84% of the specimens having corrosion-caused cracks.

[The term "corrosion-caused cracks" is used deliberately, in order to differentiate between obvious tensile distress associated with corrosion vs. the network of fine "crazing" cracks visible on the surface of most specimens.]

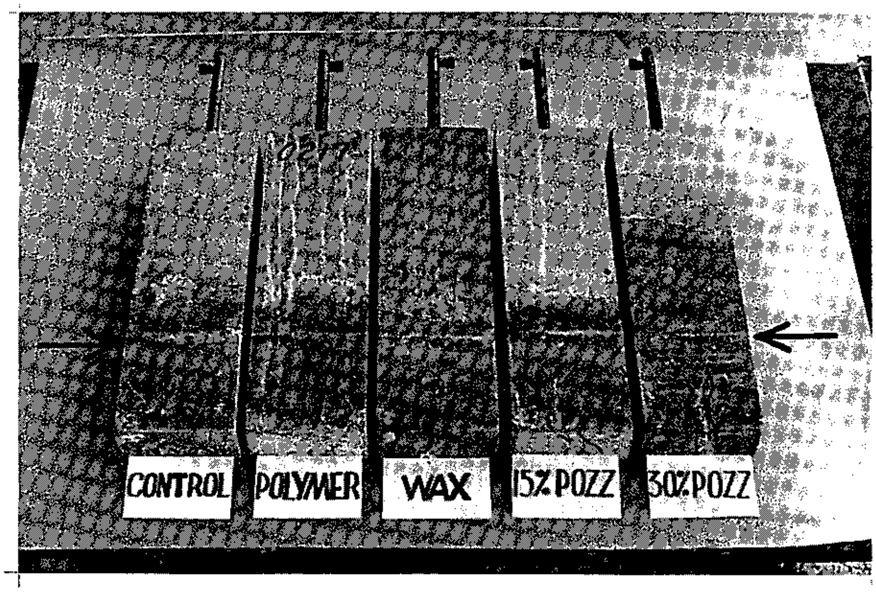
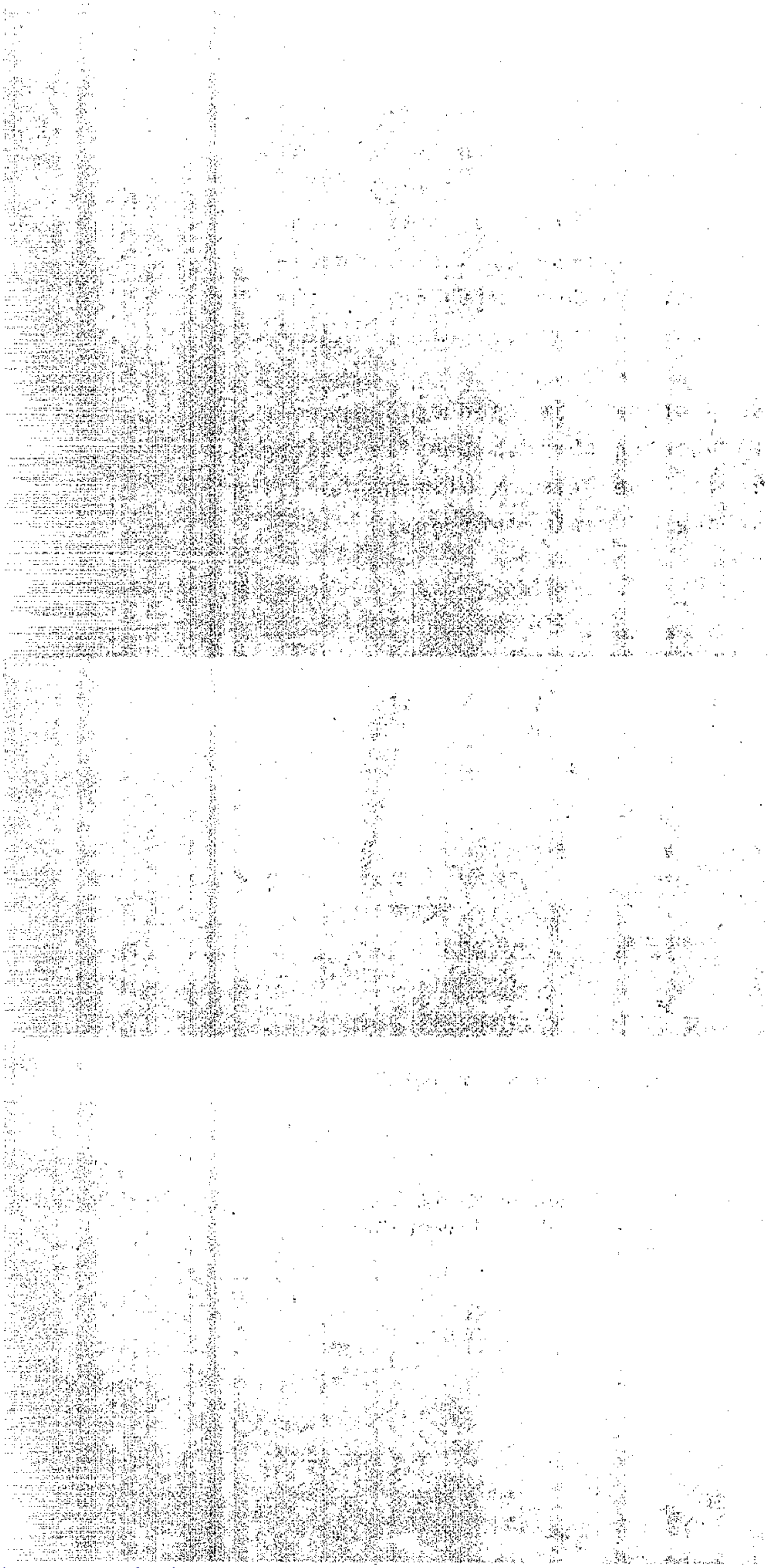


Figure 3. Cracked Specimens Showing Corrosion Cracks (outlined). Water Level Marks are Visible (Arrows).



It was also noticed that the "crazing" of all the non-wax specimens was almost invisible when their surface was dry, and slight dampening was needed to make them prominent. On the other hand, the Internally Sealed (Wax) specimens exhibited a distinctive network of fine "crazing" which remained visible even when their surface was dry.

Figure 4. Close view of three moistened specimens, showing pattern or surface "crazing" cracks

The original treatment of the wax-containing specimens consisted of heating them in a 212°F (100°C) oven for 1.5 hours. Their internal temperature, as checked by embedded thermocouples, had exceeded 185°F (85°C), the melting point of the wax after one hour.

Breaking open one of the specimens and viewing the matrix under a 3-dimensional microscope indicated that the wax beads had partially melted near the surface, but not melted at depth. A comparison was made with a 4-inch core taken from an internally-sealed bridge deck placed in 1976. Subsequent heating of this deck brought concrete surface temperatures to 350°F (177°C)±. The proportion of melted wax beads, and general appearance of the laboratory specimen surfaces, matched the appearance of the bridge deck core at a depth of 2 inches (2.5 cm)± below its surface (See Figures 5 and 6).

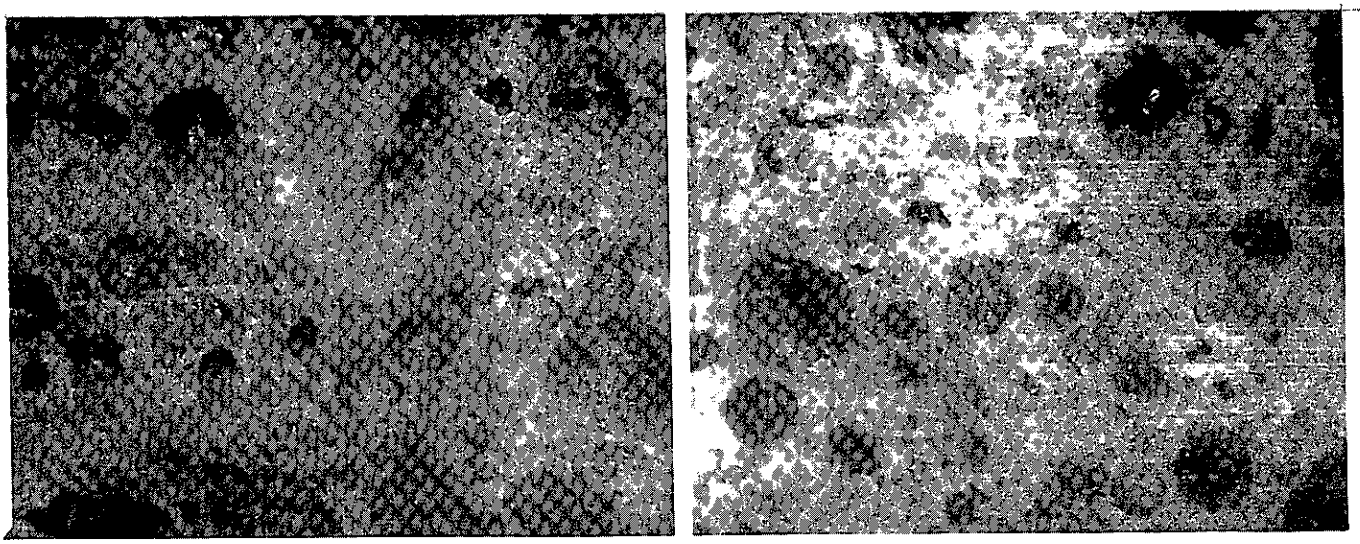


Figure 5. Microphotographs(25X) of Internally Sealed Bridge Deck Core. Left, Near the Surface, all wax has melted. Right, 2" deep, wax is only partially melted.

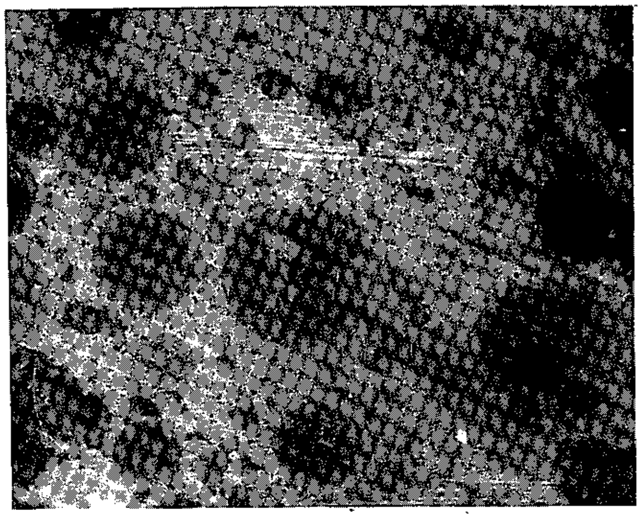


Figure 6. Microphotograph(25X) of Internally Sealed Laboratory Concrete Specimen, Near the Surface. Note Similarity of Melting with Right Photo of Figure 5.

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5. K. C. Clear, S. W. Forster, "Internally Sealed Concrete: Material Characterization and Heat Treating Studies", Federal Highway Administration Report No. FHWA-RD-77-16, Interim Report, March 1977.

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APPENDIX A

CORROSION SPECIMEN MIX DESIGNS

CONTROL,AND POLYMER IMPREGNATED

TRANSPORTATION LABORATORY

CONCRETE MIX DESIGN WORK CARD

Mix No.

Max. Size Agg. 0.75

Use Control, and P.I.C. corrosion test

Design By R.Spring		Checked by				Date 9/22/75
	Source	Lab. No.	%Abs.	SSD Sp. Gr.	Sp. Gr. X 62.4	Quantity
Rock	Teichert-Perkins	Stock	0.8	2.71	169.1	50 % by Vol.
Sand	Teichert-Perkins	Stock	1.5	2.65	165.4	50 % by Vol.
Cement	Perm. Type II					7 sks/cu. yd.
Admix.						/sack

DESIGN FOR 1 CUBIC YARD

	Absolute Volume	SSD Weight Lbs.	Sieve Size	% Pass	% Each Size
Cement (478) 7	3.35	658.0	2 1/2		
Water W/C = 45%/sack	5.05	315.0	2		
Air at 2 %	0.54	———	1 1/2		
Volume of Paste	8.94	———	1		
Volume of Agg.	18.06	———	3/4		
Rock % by Vol.	9.03	1527.0	3/8		
Sand % by Vol.	9.03	1493.6			———
Totals	27.00	3993.6	4		
Theo. Wt. Cu. Ft.	———	147.9	8		
			16		
Aggregate Weights For 1.35 Cu. Ft.			30		

	SSD	Dry	%Moist	Batch Wts.	Sieve Size
					50
Rock	76.35	75.74	0.2	75.89	100
Sand	74.70	73.60	0.3	73.82	200
Total	151.05	149.34		149.71	

MIX DATA

Batch #	1	2	Ave.1&2	4	5	Ave.4&5
Unit Wt.	150.05	150.05	150.05	150.25	150.05	150.15
Slump	3"	3"	3"	3.25"	3.5"	3.375"
% Air	1.6%	1.7%	1.65%	1.7%	1.6%	1.65%
Yield	1.324	1.324	1.324	1.322	1.324	1.323
Cem. Factor	7.14	7.14	7.14	7.15	7.14	7.145
W/C Net	42.1	42.1	42.1	42.1	42.1	42.1
W/C Total	47.1	47.1	47.1	47.1	47.1	47.1
Admix. (Amt.)						
Date Made	9/29/75	9/29/75	9/29/75	10/1/75	10/1/75	10/1/75

TL-551

INTERNALLY SEALED

TRANSPORTATION LABORATORY

CONCRETE MIX DESIGN WORK CARD

Mix No.
Max. Size Agg. 0.75
Use I.S.C. (wax)
corrosion test

Design By R.Spring		Checked by				Date 9/22/75
	Source	Lab. No.	%Abs.	SSD Sp. Gr.	Sp. Gr. X 62.4	Quantity
Rock	Teichert-Perkins	Stock	0.8	2.71	169.1	50 % by Vol.
Sand	Teichert-Perkins	Stock	1.5	2.65	165.4	50 % by Vol.
Cement	Perm. Type II					7 sks/cu. yd.
Admix.	Wax(25% Montan,5% Parafin)			0.935	58.3	16.66#/sack

DESIGN FOR 1 CUBIC YARD

	Absolute Volume	SSD Weight Lbs.	Sieve Size	% Pass	% Each Size
Cement (.478)	3.35	658.0	2 1/2		
Water W/C = 45#/sack	5.05	315.0	2		
Air at 2 %	0.54	—	1 1/2		
Volume of Paste	8.94	—	1		
Volume of Agg.	18.06	—	3/4		
Rock 50 % by Vol.	9.03	1527.0	3/8		
Sand 42.6% by Vol.	7.03	1162.8			
	2.00	116.6			
Totals	27.00	3779.4	4		—
Theo. Wt. Cu. Ft.	—	139.98	8		
			16		

Aggregate Weights For 1.35 Cu. Ft.

	SSD	Dry	%Moist	Batch Wts.	Sieve Size	% Pass	% Each Size
					30		
					50		
Rock	76.35	75.74	0.2	75.89	100		
Sand	58.14	57.27	0.3	57.44	200		
Wax	5.83	5.83		5.83			
Total	140.32	138.84		139.16			

MIX DATA

Batch #	1	2	Average	4	5	Ave.
Unit Wt.	142.1	142.1	142.1			
Slump	3.5"	3"	3.25"			
% Air	1.6%	1.7%	1.65%			
Yield	1.332	1.323	1.3275			
Cem. Factor	7.09	7.14	7.115			
W/C Net	45.8	42.4	44.1			
W/C Total	48.2	46.6	47.2			
Wax	5.83#	5.83#	5.83#			
Date Made	9/24/75	9/24/75	9/24/75			

TL-551

15% POZZOLAN, 85% PORTLAND CEMENT

Mix No. 15% Pozzolan pulling from 7 sack mix

Max. Size Agg. 0.75

Use Pozzolan Corrosion Test

TRANSPORTATION LABORATORY

CONCRETE MIX DESIGN WORK CARD

Design By P.E.Mason	Checked by	Date 10/3/75				
	Source	Lab. No.	%Abs.	SSD Sp. Gr.	Sp. Gr. X 62.4	Quantity
Rock	Teichert-Perkins	Stock	0.8	2.71	169.1	50 % by Vol.
Sand	Teichert-Perkins	Stock	1.5	2.65	165.4	50 % by Vol.
Cement	Perm. Type II			3.15	196.56	5.96 sks/cu. yd.
Admix.	Pozzolan Aerox			2.40	149.76	16.4#/sack

DESIGN FOR 1 CUBIC YARD

	% by Wt.	Absolute Volume	SSD Weight Lbs.	Sieve Size	% Pass	% Each Size
Cement (478)	0.85 0.15	2.85 0.65	560 98	2 1/2		
Water W/C = 52.7#/sack		5.03	314	2		
Air at 1.5%		0.40	—	1 1/2		
Volume of Paste		8.93	—	1		
Volume of Agg.		18.07	—	3/4		
Rock % by Vol.		9.04	1529	3/8		
Sand % by Vol.		9.03	1494			—
Totals		27.00	3995	4		
Theo. Wt. Cu. Ft.		—		8		
				16		
				30		
				50		
				100		
				200		

Aggregate Weights For 1.35 Cu. Ft.

	SSD	Dry	%Moist	Batch Wts.
Rock	76.45	75.84	0.2	75.99
Sand	74.70	73.58	0.3	73.80

MIX DATA

Batch #	1	2	Average	4	5	Ave.
Unit Wt.	147.4	147.6	147.5			
Slump	4"	3.5"	3.75"			
% Air	1.4%	1.4%	1.4%			
Yield	1.364	1.360	1.362			
Cem. Factor	5.90	5.91	5.905			
W/C Net	57.1	55.9	56.5			
W/C Total	62.7	61.7	62.2			
Admix. (Amt.)	4.9#	4.9#	4.9# (Pozzolan)			
Date Made	10/6/75	10/6/75	10/6/75			

TL-551

30% POZZOLAN, 70% PORTLAND CEMENT

Mix No.	30% Pozzolan pulling from 7 sack mix
Max. Size Agg.	0.75
Use	Pozzolan Corrosion Test

TRANSPORTATION LABORATORY

CONCRETE MIX DESIGN WORK CARD

Design By P.E.Mason		Checked by			Date 10/3/75
	Source	Lab. No.	%Abs.	SSD Sp. Gr.	Sp. Gr. X 62.4	Quantity
Rock	Teichert-Perkins	Stock	0.8	2.71	169.1	50 % by Vol.
Sand	Teichert-Perkins	Stock	1.5	2.65	165.4	50 % by Vol.
Cement	Perm. Type II			3.15	196.56	4.9 sks/cu. yd.
Admix.	Pozzolan Aerox			2.40	149.76	40.4 #/sack

DESIGN FOR 1 CUBIC YARD						
	% by wt.	Absolute Volume	SSD Weight Lbs.	Sieve Size	% Pass	% Each Size
Cement (478)	0.70 0.30	2.34 1.32	460 198	2 1/2		
Water W/C =67.3#/sack		5.29	330	2		
Air at	1 %	0.27	———	1 1/2		
Volume of Paste		9.22	———	1		
Volume of Agg.		17.78	———	3/4		
Rock	50 % by Vol.	8.89	1,503	3/8		
Sand	50 % by Vol.	8.89	1,470			
Totals		27.00	3,961	4		
Theo. Wt. Cu. Ft.		———	146.7	8		
				16		
Aggregate Weights For 1.35 Cu. Ft.				30		
	SSD	Dry	%Moist	Batch Wts.	50		
Rock	75.15	74.55	0.2	74.70	100		
Sand	73.50	72.40	0.3	72.61	200		

MIX DATA						
Batch #	1	2	Average	4	5	Ave.
Unit Wt.	144.6	144.6	144.6			
Slump	3.5"	3.5"	3.5"			
% Air	1.6	1.5	1.55			
Yield	1.382	1.382	1.382			
Cem. Factor	4.78	4.78	4.78			
W/C Net	75.1	75.1	75.1			
W/C Total	81.8	81.8	81.8			
Admix. (Amt.)						
Date Made	10/9/75	10/9/75	10/9/75			

TL-551